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**SURVEY AND EVALUATION
OF ATOMIC ENERGY RAW MATERIALS**

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SURVEY AND EVALUATION OF ATOMIC ENERGY RAW MATERIALS

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A.5.I.2

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1. INTRODUCTION

During recent years there has been an unprecedented development in geophysical, geochemical and geobotanical techniques, many of which have been applied in the search for atomic energy raw materials. Indeed, so many methods are available, and so vociferous are their respective advocates, that the non-specialist is often in a quandary in deciding which to employ in a particular region. Experience gained in the past fifteen years has clearly demonstrated to us that a prerequisite of all successful prospecting is basic geological information and a knowledge of the geochemistry of the element being sought. In undertaking the systematic exploration for any type of mineralization, the first essential step, therefore, is to obtain as much geological information on the circumscribed area as is available. From this it is usually possible for an experienced radiogeologist to decide whether the area is geologically, geochemically and structurally favourable for the development of ore bodies. Where geological knowledge is lacking it is often beneficial to obtain preliminary information from the examination of aerial photographs. It is not possible in the space available to list all criteria which may indicate potential areas of mineralization, but some of those having a particular application to the search for uranium and thorium deposits are briefly discussed.

2. TYPES OF DEPOSIT

Uranium and thorium deposits may be classified in a variety of ways. One convenient method based on mode of occurrence is given in Table 1 and may be a useful guide to the selection of localities in which similar deposits may occur. Three generalizations worth bearing in mind in connection with the search for radioactive minerals are:

- (a) The major deposits of uranium at present known are located in ancient crystalline rocks or in permeable sediments of younger age, for example, in conglomerates or sandstones.
- (b) Uranium minerals are associated regionally with acid rather than basic igneous rocks, although the latter may locally act as favourable hosts.
- (c) Thorium minerals occur mainly in placer deposits, which may be recent or fossil, and in veins.

3. GEOLOGICAL GUIDES

Specific geological guides to uranium mineralization vary from province

to province, though some have a wide application in the search for new occurrences. The more important of these are:

(a) Petrogenetic associations. The association of uranium with acid igneous rocks such as granites, granodiorites and rhyolitic lavas has been noted in many parts of the world and it is considered that this results from their common origin. Uranium is frequently found in upper and peripheral portions of granitic intrusions and these should always be examined carefully. Anticlinal and domal uplifts suspected of being associated with such igneous rocks, even though these do not outcrop, are also worthy of attention, particularly the flanks of the uplift.

(b) Structural control. The concentration of uranium, and of other metals, is frequently controlled by structural features in the host rock. The most important of these are tension fractures, intersections of faults, zones of shattering or brecciation, and tight folding in incompetent strata. In relatively flat-lying permeable sediments such as sandstones and conglomerates, concentrations of metals frequently occur where there are sharp changes in texture and composition. One of the best hosts for ore minerals is a coarse-grained sandstone with variations in texture.

(c) Mineral associations. Vein-type deposits of pitchblende and uraninite are commonly associated with copper, lead, zinc, cobalt, nickel and silver ores. Thus all known occurrences of these metals merit examination with modern prospecting instruments. Similarly, any known occurrence of copper, iron, vanadium, selenium or arsenic in sedimentary rocks should be examined as uranium is often found in such an environment.

(d) Chemical affinities. Uranium is frequently enriched by sorption or chemical combination in carbonaceous, phosphatic or ferruginous sediments and although these are not usually as high grade as hydrothermal deposits they may contain vast resources for future use. For example, there are large tonnages of uranium in lignites in North and South Dakota at grades exceptionally as high as 0.2 per cent U_3O_8 ; marine black shales in Sweden also contain many thousands of tons of uranium at grades of up to 0.03 per cent U_3O_8 .

(e) Absolute age of mineralization. The determination by isotopic ratio methods of the absolute age of radioactive mineralization and of the intrusion of acid igneous rocks in areas where primary uranium mineralization is known to occur is of considerable importance. This can give the age of the latest phase of mineralization and so enable younger rocks to be eliminated as likely environments in which to find further uranium. An excellent example of the value of age determination is afforded by work on ore from the Colorado Plateau which showed that the mineralization was much younger than the host rock in which it was generally found. This led to the search being extended from a fairly narrow stratigraphical horizon of Jurassic rocks to rocks older and younger in age and resulted in the discovery of new and important ore fields.

4. METHODS OF PROSPECTING

Once a favourable region has been delineated, a decision has to be taken on which of the many tools at the prospector's disposal should be used in the search. As there is no general guide to this, the various methods are discussed separately and indications given as to where they may best be applied.

(a) Aeroradiometric surveys. One of the most economic, and certainly most thorough, means of covering a large area is by an aeroradiometric survey. Costs per line-mile range from £2.10s. to less than £1, and can be kept to a minimum

by ensuring that radiometric equipment is installed in all aircraft undertaking other investigations on a grid pattern at a suitable flying height. Aero-radiometric surveying can normally be justified only if the geological environment has been shown to be favourable and if the following conditions can be fulfilled:

- (i) terrain relief is such that the aircraft can maintain the specified ground clearance with an accuracy of ± 20 per cent.
- (ii) the detecting instrument has a sensitivity such that it can be flown at a height of 500 ft. and a spacing of 1000 ft. and detect anomalies with a concentration factor of 10 or less¹.
- (iii) climatic conditions are suitable for low level flying.
- (iv) terrain covered by dense vegetation, muskeg, desert sand or other superficial deposit is avoided except under special circumstances.
- (v) a team of experienced geologists is available to assess anomalies on the ground, as this cannot be done from the aeroradiometric records.

(b) Car-borne surveys. A number of important uranium deposits have been discovered by car-borne radiometric equipment. This method has the advantage of low cost per mile of traverse, but suffers from being limited to areas accessible to vehicles and to the detection of radioactivity in a narrow strip adjacent to the track of the vehicle. The performance of recent equipment has been improved by using a large diameter scintillation crystal as detector and mounting this well above the vehicle to increase coverage.

(c) On-foot surveys. Surveys on foot with Geiger-Müller or scintillation counter should be a routine measure in normal geological mapping or may be used in areas not suited to aeroradiometric or car-borne surveys. There is little to choose between a good G-M counter and a scintillometer, though the latter is generally preferred since it is capable of detecting a low-level anomaly more readily than a G-M counter and can be used at a faster traverse speed. The G-M counter has the advantage of being more easily adaptable for beta-radiation surveys, for the assay of samples in the field and for the survey of shallow boreholes.

(d) Radon sampling. The quantitative determination of the concentration of radon in 'ground air' has been applied successfully in recent years as a method of detecting deposits of uranium obscured by glacial and other superficial deposits. The technique is particularly suited to secondary surveys in an area known to be favourable to uranium mineralization. The apparatus used is a portable alpha-scintillation counter adapted to analyse air extracted from shallow probe holes rapidly and at low cost.

(e) Geochemical techniques. Geochemical techniques have not been widely used in the detection of uranium or thorium because of the relative ease with which the natural radiations from these elements can be detected by the physical methods referred to above. However, a variety of analytical methods have been devised to detect uranium in water samples at levels of down to 0.2 $\mu\text{g/l}$. A colorimetric method has been developed which enables contents of down to 1.0 $\mu\text{g/l}$ of uranium to be determined at the stream side thus enabling an immediate follow-up of any anomalies to be made. The content of uranium in run-off water is influenced by factors such as pH, degree of dilution, presence of organic matter, bicarbonate ion content, and the solubility of the source mineral, and may be unreliable as a guide to the whereabouts of workable uranium deposits. The technique has its most useful application in country difficult of access - for example in heavily

¹ Concentration factor = area of anomalous activity in square yards x percentage equivalent U_3O_8 .

forested mountain terrain - where it helps to delineate those river basins or tributary valleys in which uranium mineralization is most likely to occur.

(f) Geobotanical methods. Geobotanical methods of sampling and analysing plants in order to detect concentrations of uranium have found a limited application in semi-arid regions where plant roots penetrate to depths of up to 70 feet and may give indications of mineralization not detectable at surface by physical methods.

5. ASSESSMENT OF OCCURRENCES

The evaluation of occurrences of uranium or thorium is undertaken by the techniques normally employed in assessing concentrations of other metallic ores. In addition, however, many of the radiometric methods employed in the search for uranium can be modified to aid in mineral appraisal.

(a) Preliminary examination. The preliminary examination of an area of anomalous radioactivity is normally undertaken by traversing it on a grid pattern with a portable G-M or scintillation counter and preparing an isorad map showing areas of equal radiation intensity. This, together with available information on geology, topography, drainage, secondary mineral development and the equilibrium condition of the ore minerals, helps to locate the mineralization more precisely and indicates the type of occurrence. Subsequent procedure will depend much on experience, but if further work seems justified this will normally involve trenching, sampling and exploration drilling.

(b) Gamma-logging of boreholes. Where core-recovery from diamond-drill holes is poor, gamma-logging equipment may be used to locate and determine the approximate grade of any mineralization. Caution should be exercised in correlating gamma-log readings with grade of ore, since this is only likely to be reliable in particular circumstances and is by no means universally applicable.

(c) Radiometric assaying. At all stages from the location and preliminary examination of an occurrence, a G-M ratemeter with a beta-probe attachment can be used for 'in situ' assaying and for reducing the number of samples requiring chemical analysis. Such equipment may also be used to undertake fairly accurate assays in the field under conditions where the transport of a large number of samples might prove difficult. A beta-probe attachment or small beta-sensitive instrument is also invaluable as a mine-control instrument for delineating material of ore grade.

6. BERYLLIUM DETECTION AND ASSAY

The detection and assay of beryllium ores in the field is facilitated by the use of portable electronic instruments, employing boron trifluoride tubes to measure the neutrons emitted when beryllium is bombarded by the gamma rays from the isotope antimony -124. 'In situ' assays can be made in the field with great rapidity using these instruments, with the result that a high statistical accuracy is achieved. Similar equipment, made for laboratory use, enables accurate assays of beryllium to be made without the need of costly and time-consuming chemical analyses. Indeed, the use of a (γ, n) laboratory instrument can effect an annual saving of as much as £30,000 per equipment as compared with the normal charge made for wet chemical assays. Both field and laboratory instruments are capable of detecting less than 5 ppm BeO.

7. CONCLUSIONS

There is ample scope for new specialized techniques to aid in the discovery and assessment of the raw materials of the atomic energy industry. In

particular, there is a requirement, which may be fulfilled in the near future, for the determination of specific elements in the field. Whatever the role of new specialized techniques, however, there is little doubt that successful prospecting for future supplies of raw materials will depend on a better understanding of the fundamental geological and geochemical processes involved in controlling the deposition of ore minerals in the earth's crust.

Table 1

Classification of Uranium and Thorium Deposits

<u>Type</u>	<u>Primary Minerals</u>	<u>Normal Grade</u>	<u>Examples</u>
Hydrothermal (low to medium temperature)	Pitchblende Coffinite Uraninite	$> 0.2\% \text{ U}_3\text{O}_8$	France; Portugal; Shinkolobwe; N.W. Canada (Great Bear Lake, Lake Athabasca)
Hydrothermal (high temperature)	Davidite Monazite	$0.1 - 0.2\% \text{ U}_3\text{O}_8$ up to $5\% \text{ ThO}_2$	Radium Hill, Australia; Mavuzi, Mozambique; Van Rhynsdorp, S. Africa
Pyrometamorphic replacement	Uraninite Allanite	$0.04 - 0.1\% \text{ U}_3\text{O}_8$	Mary Kathleen, Australia
Pegmatite	Uraninite Betafite Euxenite Davidite	Sometimes $0.1 - 0.2\% \text{ U}_3\text{O}_8$, but not normally workable	Bancroft, Canada; Mozambique; S. Rhodesia; N.S.W., Australia
Disseminated	Uraninite Coffinite Brannerite Pitchblende	$0.03 - 0.2\% \text{ U}_3\text{O}_8$	Witwatersrand; Blind River; Colorado Plateau
Sedimentary phosphates, lignites and shales	No discrete uranium minerals	$0.01 - 0.03\%$; down to 0.006% U_3O_8 as by-product	Florida; N. and S. Dakota; Västergötland, Sweden
Placer	Monazite Thorianite Thorite	$> 0.01\% \text{ ThO}_2$	Travancore, India; Brazil; Indus R., Pakistan

